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Whole-Body Dosimetry of Microwave Radiation in Small Animals: The Effect of Body Mass and Exposure Geometry

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16. ABSTRACT

Whole-body absorption of 2450-MHz radiation was measured in rats that ranged from 6 to 440 grams and mice that ranged from 30 to 50 grams. Simultaneous exposure of groups of animals in varying numbers and various configurations were made under free-field conditions in an electrically anechoic chamber. Measurements of whole-body absorption were made with twin-well calorimeters. The results indicate that, for animals within a given narrow range of body mass, individual rates of absorption may, at the extreme, vary by a factor of seven. One implication of this variability is that studies of dose-response relations may be confounded unless power densities of incident radiation are sufficiently different to provide nonoverlapping dose rates. Comparisons of measured doses to predicted values as derived from a spherical shell model show considerable variations of observed from predicted values. Specific relationships of the SAR to the position and mass of the animals are presented.

specific absorption rates

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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the heater's power could be calculated from the known resistance and the monitored voltage. Calibration of each unit was accomplished by applying energy at a rate of approximately 12.8 watts for a measured period of time, and by recording the calorimeter's output on a strip chart. The area under this curve was computed and a table was created relating absorbed energy and area. Maximum estimates of instrument error were ± 0.5% for area determination, and ± 0.1% for voltage and resistance measurements.

The procedure used in all exposure conditions was to sacrifice pairs of animals of similar mass, place them in thin plastic bags and allow them to come into thermal equilibrium with each other in an insulated container. One of the pair was then exposed along with live animals in the experimental-exposure array. The power density of the incident field was 50 mW/cm^2 and the duration of radiation was 10 minutes. The radiated animal and its control were placed in the calorimeter's wells and a strip-chart recording was made as the calorimeter returned to equilibrium. The area under the curve of equilibrium was calculated and was converted to a measure of absorbed energy by the calibration table. Specific absorption rates (SARs) were then determined from the animals' masses and the absorbed energy was scaled from 50 mW/cm^2 to the free-field exposure value that was used in the original animal experiment.

During the interval of time between exposures of the animals and their placement in a calorimeter, some thermal energy was lost through radiation and convection. The estimate of this loss is approximately 5% of the total energy gained from microwave radiation, thus the SARs are underestimated by this amount.

3. RESULTS AND DISCUSSION

The two series of absorption measurements that are reported here reflect the data from experiments on mice and rats. The procedure was not based on a systematic progression from simple to complex exposure geometries but, rather, was based on dosimetric measurements as they applied to specific experiments. The SARs have been scaled to a power density of 10 mW/cm^2 of incident radiation, which was actually employed in the biological experiments. Predicted SARs were derived from the concentric, spherical-shell model [*Shapiro et al.*, 1971] using estimates of dielectric values and sizes of spheres. The model is a single sphere made of concentric shells of skin, fat, bone, muscle, etc., exposed to a plane wave [*Weil*, 1975]. Multiple spheres were not included in this model, and thus, it is not a true representation of actual conditions. The purpose for its inclusion is not to assert any validity of the predictive model but rather to indicate that in lieu of making the measurement of absorption, we would have assumed the value shown by this imperfect model.

The first series of absorption measurements was made on two different arrays of CD1 mice. A summary of data for the mice is shown in Table 1. In the first experiment of this series, 15 mice were exposed in a 3-column array of 5 mice each; the mice were individually contained in a cubic, polyethylene box, 6 cm on edge. Columns were formed with the boxes touching, and each column was spaced from the other by 14 cm. In the second experiment, 25 mice were exposed in a rectangular array of 5 rows by 5 columns. Spacing in the row was 6 cm, and between columns, 9 cm. In each of the arrays, the animal containers were secured in place with a Styrofoam sheet that contained cutouts for the boxes.

In the 3 by 5 array, the dose rates differed from the highest to the lowest rate by a factor of 3.8. This difference is a compounded number reflecting the contributions of such variables as the mass and position of the animals in the array. It should be noted that the spread is reduced to a factor of 2.6 in the 5 by 5 array. This observation supports the speculation that mixing, presumably caused by reflections from moving animals, will improve the uniformity of whole-body absorption in experiments that involve simultaneous exposure of a group of animals. This mixing characteristic of multiple-animal exposures had previously been shown by *Chernovetz et al.* [1975] in the case of phantoms moved about in a multimodal cavity. To permit comparisons of thermal loading by microwave irradiation, the estimated basal metabolic rate of mice and rats has been included in Table 1 (cf. also Table 3). For radiation of mice at a power density of 10 mW/cm^2 the averaged dose rate is no more than 60% of the basal metabolic rate [*Kleiber et al.*, 1956]. The observed dose rates were consistently lower than the predicted values. This decrease

TABLE 1. Specific absorption rates in mice exposed at 10 mW/cm^2 (2450 MHz). Assumed BMR = 6.4 mW/g [*Kleiber et al.*, 1956].

EXPOSURE MATRIX	MASS g	RANGE OF DOSE RATES mW/g	AVERAGED SAR mW/g	PREDICTED RANGE OF SARs mW/g
3 × 5	26 - 45	4.8 - 1.3	3.2 ± 1.3[a] (47)[b]	5.1 - 4.5
5 × 5	20 - 35	6.8 - 2.6	4.2 ± 0.9 (45)	5.3 - 5.0

[a]Standard Deviation.
[b]No. of Measurements

TABLE 2. Absolute and relative dose rates (mW/g) in mice as a function of position in a 5 by 5 array[a].

13[b] 5.7[c] (3)[d] 0.3[e] 1.0[f]	14 4.5 (6) 0.6 0.8	15 3.9 (6) 0.7 0.7
18 4.7 (6) 0.6 0.8	19 4.3 (5) 0.9 0.8	20 3.5 (6) 0.9 0.6
23 1.5 (6) 0.6 0.6	24 4.9 (4) 0.7 0.9	25 3.5 (3) 1.0 0.6

[a]Power Density 20 mW/cm^2 [c]Averaged Absolute Dose Rate [e]Standard Deviation
[b]Position No. in Array [d]No. of Measurements [f]Relative Dose Rate

probably reflects the limitation of the predictive model, i.e., the assumption of a single target of uniform shape and dielectric properties.

The use of the 5 by 5 exposure array represented an attempt to reduce the spread of absorption values and to determine whether there is a dose-rate dependence on position. The following discussion is confined to the nine positions on the bottom right quadrant of the array (positions 13, 14, 15, 18, 19, 20, 23, 24, 25). For mice exposed to radiation at a power density of 10 mW/cm^2, the data in Table 2 show the absolute SAR as a function of position. The relative SAR as normalized to position 13 is also included. The data of Table 2 clearly reveal that SAR is a function of position in the array. The variability among SARs dictates that in repetitive exposures, animals must remain in a designated position throughout the experiment. Although decreasing SARs in animals that were remote from the center of the exposure plane were expected, the higher than expected value in position 24 was not anticipated. Thus, variations of SAR as a function of position represent a major variable that must be taken into account in assessing biological effects.

The second series of absorption measurements, which were made on Sprague-Dawley rats is summarized in Table 3. This was an extensive series of measurements, which were made from birth to 92 days of age, during which the animals grew from 6 grams at birth to a final mass in excess of 400 grams. The basic configuration for this exposure employed 12 Plexiglas boxes that were placed in 2 rows of 6 boxes each. The boxes were further subdivided by Plexiglas sections into uniform compartments. Thus as the animals grew, each box contained eight or four rats, or even a single rat. Animals of similar mass were located in the 12 boxes during any given exposure. The summary of data in Table 3 indicates the number of animals per box for each range of mass. In the range of 110 to 200 grams, four animals of

TABLE 3. Specific absorption rate in rats (mW/g) as a function of mass[a]. Assumed BMR = 4.8 mW/g [*Swan*, 1974].

EXPOSURE CONDITION (NO./BOX)	MASS (g)	AVERAGED SAR (mW/g)	PREDICTED SAR (mW/g)
8	6 - 10	(13)[b] 9.4 ± 2.7[c]	7.7
4	40 - 60	(14) 4.9 ± 2.6	4.5
4	70 - 110	(10) 3.2 ± 1.8	3.3
4.1	110 - 200	(9) 1.8 ± 0.7	3.0
1	310 - 350	(12) 1.4 ± 0.4	2.2
1	430 - 440	(2) 0.9 ± 0.8	2.0

[a] 10 mW/cm^2, 2450 MHz
[b] No. of Measurements
[c] Standard Deviation

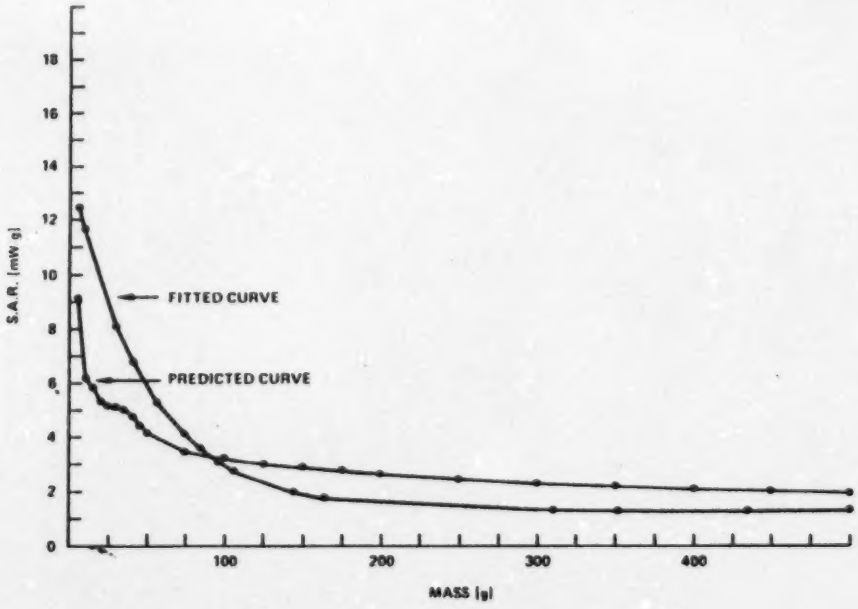

Fig. 1. Observed and predicted dose rates in mW/g as a function of body mass in rats exposed to 10 mW/cm^2.

masses to 160 grams were exposed. As expected from predictions of SARs of single targets of varying size [*Weil*, 1975], the results demonstrated a decrease of SAR as a function of mass.

The data are also plotted in Figure 1. The best line-of-fit for the observed data is a decreasing exponential. In multiple targets of individual masses to 70 grams, the predictive model underestimated the SAR by as much as 100%. At greater masses, the model overestimated the observed values by approximately 50%. The actual absorption rate at a power density of 10 mW/cm^2 exceeds the estimated basal metabolic rate (BMR) of rats that are less than 50 grams and is as much as 200% greater than the BMR of newborn animals [*Swan*, 1974].

4. SUMMARY AND CONCLUSIONS

The comparison of SARs as observed in multiple-animal exposures to 2450-MHz radiation indicates that a greater number of targets reduces the interanimal variability in whole-body absorption. However, the spread of SARs throughout a matrix is sufficiently great that arbitrary choices of power density in dose-response studies is inadvisable.

The position of an animal in an exposure matrix significantly affects the SAR, thus, casting doubt on the value of relating biological effects to a single measurement of power density.

The measured SARs in multiple-animal exposures were significantly different from the rates predicted by a single-target model. The difference indicates a limitation on the ability of models to relate to the multiple-animal exposures that are commonly used in biological research.

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